chromosomes, is confined to the male line and it is possible that its loss of function is due to a lack of variable reaction. It experiences in effect, a most intensive form of inbreeding and shows the characteristic results of such unvarying reactions. For it, there is no opportunity to eliminate greater or less variables, as is the case with the x-element during maturation in the female. The ultimate problem is, of course, to determine why such a difference between homologous elements should exist.

THE STUDY OF THE SEDIMENTS AS AN AID TO THE EARTH HISTORIAN

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Objectives of the Earth Historian.—We are, of course, still immensely far from our ultimate goal, which is a complete understanding of all the past states and events of the earth, or as Professor Salisbury used to put it, "the complete geographies of all past epochs." Progress toward this unreachable goal will be most favored if the advance is made rather uniformly, all along the front. It is true that such progress is often made by pushing out salients, but the further extension of such salients is usually impossible without corresponding support from the flanks.

In the past we have gone ahead much farther along certain lines in geologic history than along others. The history of life and of faunal succession has been cultivated assiduously for generations and is, on the whole, much better understood than other phases of the subject. Although not so well known in detail, the history of diastrophism is now fairly well blocked out and the mere continuation of studies already under way is likely to afford us in the near future a serviceable understanding of the sequence of major earth movements.

The most backward points in the general advance just now are in two sectors: That of the history of climate, and that of the principles of chronology and correlation.

The importance of climate arises from the fact that it is one of the most powerful factors, if not indeed the dominant factor, controlling not only the sculpture of the land but the nature of the deposits that are made both on land and in the sea.

Secondly, the principles of correlation must be understood better than they are now, before we can bring into their proper time relations the various events and conditions of which the sediments give us record. In spite of the impressions in elementary text books of geology, I think it will be generally admitted, by those who have carefully considered the question, that we do not yet know these principles with satisfactory accuracy. If we did, we should

not have such anomalies as the actual interbedding of strata in Montana containing marine invertebrates assigned to the Cretaceous with those containing land plants identified as Eocene; or as the Triassic in Idaho resting conformably on rocks containing only Pennsylvanian fossils. Many other cases of similar perplexity will occur to those who have had much to do with age questions in stratigraphy. All things considered, it seems to me that the improvement of correlation methods and a more general acceptance of these improvements is at the present time the thing most to be desired by the earth historian, for nowadays it is one of the chief causes of friction among us.

What service can the study of the sediments and sedimentary rocks render in connection with these two problems? First it offers the best and most comprehensive means of working out the history of climate. We already understand rather fully the climatic significance of such deposits as beds of coral limestone, of tillite, and of saline formations. We have probably reached a similar comprehension of the red beds, loess, and certain other types, although we are not yet fully agreed among ourselves regarding them. Before long we may expect to know as fully the climatic significance of the coal-bearing gray sediments, and eventually even of most of the marine deposits. For even among the, latter no matter how great the importance of the work of bacteria, algae, foraminifera, and other organisms is, it becomes increasingly evident that the very activities and processes of these organisms are largely dominated by climate, either directly or indirectly, and that they are forced to make a record of climatic changes in the marine sediments to which they contribute. For example, the prevalence of siliceous in place of calcareous ooze in the Antarctic Ocean is probably due to biochemical factors that depend on climate.

The study of climatic history is not only necessary for its own sake as a division of the larger earth history, but it has an important bearing upon the attainment of the other desideratum, namely, more reliable correlations. Climatic changes are widespread in their influence. Some, like the cooling off during the last glacial period, seem to have affected the whole earth. They influence both land and sea deposits, and hence leave their impress on all sedimentary formations. In comparison with the slow progress of geologic events, the effects of climatic change are felt quickly. We seem justified in believing that altered climates do not ordinarily migrate slowly from region to region, and on this assumption it may generally be presumed that the results are essentially simultaneous over large areas. For these reasons climatic changes should serve as very delicate indicators of time relations. They are likely to be especially valuable because their record is most clear in the terrestrial sediments, where fossils—our customary reliance—are apt to be rare or absent.

From the earliest days of geology attempts have been made to correlate strata in different places by means of lithologic character. Many of these attempts have met with either failure or only partial success. In comparatively recent years, however, more refined methods have yielded much better

results. For example, Rogers and Stone in their recent study of the Lebo shale of Montana have shown that it can be identified over large areas by its andesitic particles, which record eruptions of volcanos farther west at a single epoch in Cretaceous times.

In the future it will undoubtedly be possible to make far greater use of the physical characteristics of sedimentary rocks in correlation—not so much by a direct matching of similar rocks as by an indirect process of first elaborating from the rocks the climatic and physiographic conditions and their changes in time, and then correlating these. It should in fact be as feasible to correlate by means of climatic history as to correlate by diastrophic history. Indeed it is already beginning to be the practice of the most progressive stratigraphers to make their correlations not simply on the basis of faunas nor on the basis of diastrophism, but on the compound basis of life, climate, topography, vulcanism, and diastrophism with due regard to their mutual relations and dependences and their relative values. It is my own expectation that this practice will soon become general.

What is Needed.—We may reasonably hope to understand eventually all of the sedimentary rocks at least as well as we now know any; but at present our knowledge is very uneven, being tolerably complete for some types and very slender for others. Among the sediments which are as yet but partly understood the following may be mentioned by way of illustration of our needs: limestone conglomerates and oolites, sedimentary iron ores, chert, jasper, etc., gray flags and shales with lean faunas, dolomites, phosphorites, greensands, black oily shales, lithographic limestones, and rhythmically alternating shale and limestone. Of course, there are many others.

To advance more rapidly this part of the scientific battle front, several things are needed. Among the most useful are the prolonged and intensive studies of certain modern types of deposits and the processes of their deposition, as illustrated by the investigations that have been carried on recently by T. W. Vaughan and his associates in the Florida region, as well as by the careful study of mountain stream work by G. K. Gilbert in California. Some of these problems are too large to be attacked by most individuals, but require for their successful execution the aid of our strongest scientific institutions and the cooperation of a number of investigators over a period of years.

Hardly less valuable are the close and detailed studies of ancient sedimentary rocks, such as Barrell's interpretation of the Mauch Chunk shale, the study of the western Red Beds by C. W. Tomlinson, and of the dolomites by half a dozen or more geologists in the last few years. Probably this method must be our sole reliance in the case of certain peculiar sediments which, so far as known, are not being formed on the earth at the present time. These are illustrated by the thick, rich beds of phosphorite in Idaho and perhaps by the stratified iron ores of eastern Brazil.

Our understanding can be advanced in a most helpful way also by careful experimentation, such as that on sun-cracks reported by E. M. Kindle, or the

bacteriological experiments of Drew and others on the precipitation of calcium carbonate from sea-water and the formation of oolites. On the whole there has been much too little of this sort of work in the last few decades, perhaps because sedimentary studies have been left largely to the stratigrapher who is rarely, by force of habit, a laboratory experimenter. We shall need in this work the coöperative aid of expert chemists, bacteriologists, and others not ordinarily interested in geologic matters. The whole subject of diagenesis, or simultaneous alteration of sediments, is doubtless in the province of the bio-chemists and colloid chemists, if only we could induce them to assume the task.

It might seem, at first thought, superfluous for me to recommend the thorough combing of the geological literature for material on the nature and origin of the sediments. But it is a fact, by no means sufficiently appreciated by most of us, that the amount of buried treasure of this kind is really enormous. A few years ago, while engaged in the study of phosphorite deposits, I was astonished to find that the papers published in France and England during the seventies contained a much clearer and more comprehensive interpretation of phosphatic deposits than could be found in any American text-book or reference work published since 1900. In fact, it was perfectly evident that most even of the more valuable of these foreign papers had never been seen by the authors of the compendia mentioned, nor even by Americans who had published important papers on the phosphatic rocks. I believe it is a fact that one of the greatest services that can be rendered, just now, to the advancement of our knowledge of sediments and sedimentary rocks would be the thorough investigation, digestion, and summarizing of what is already in print on the various types of sediments. It would vastly increase our effective working knowledge and might conceivably double it, for it must be clear that a fact or a theory which is lost is as useless as one that has never been found out.

Chemical analyses give much valuable information regarding sedimentary deposits. Not infrequently the general conditions of origin as well as the nature of the rock, can be inferred at once from the analysis. We have far too few of them, and it is one of the minor discouraging conditions of the study that even those we have are in many instances rendered useless by the omission of essential facts.

Furthermore, a great many analyses are published with only the most meager information regarding the source of the material. It is obviously of very little value to the sedimentationist to know that a certain analysis pertains to a Cretaceous shale from Mt. Diablo, California, because the mountain contains several distinct types of shales of Cretaceous age. In that case even the brief statement that it was a gray sandy shale with abundant fragmentary mollusks and echinoderms would greatly enhance the value of the analysis. The same benefit might be conferred by noting that the specimen came from a particular bed in a carefully described section already published. It is for this reason that the great number of analyses in Clarke's *Data of Geochemistry*,

have only a small fraction of the value to the sedimentationist that they might just as well have had if the facts had been adequately stated. We need, therefore, more analyses, more comprehensive analyses, and especially more fully annotated analyses.

Probably our broadest, even if not our deepest, fund of information for the interpretation or sedimentary formations comes from the descriptions of sections by stratigraphers and by field geologists in general. Here, as in the case of the chemical analyses, the sedimentationist meets with frequent disappointment, simply because the exact and detailed observations, which alone could make the section valuable for his purposes, have been largely or entirely omitted. We have thousands of stratigraphic sections in which successive beds are described as 'yellow sandstone,' 'gray shale,' 'fossiliferous limestone,' etc., leaving the reader to guess as best he may the significant characteristics of the strata. Of course, the author of a report usually gives descriptions that are adequate for his own purposes even if not for those of others who may go to it for light. On the other hand those geologists who make it a practice to describe colors carefully, to note textures, the presence of cross-bedding, ripple-marks, sun-cracks, nodules, forms of grains, character of cements, nature, abundance, and distribution of fossils, to say nothing of mineral content, forms of large versus small grains, type and amplitude of cross-bedding and ripple-marks and the nature of the filling in sun-cracks, are a source of joy to the student of the sediments. Unwittingly perhaps, they are rendering us a valuable service. We only regret their scarcity.

Many of us are necessarily limited in the geographic range of our first-hand study of sediments and sedimentary processes. Others who have had the good fortune to visit distant regions, and especially the less known parts of the earth, such as the tropics and the arctic countries, can often with very little trouble collect observations and material which may later, in the hands of a trained student of sedimentation, yield important information for which we might otherwise have to wait for decades. The amount of such data now on hand in American universities and museums is very small when compared with that which is available for a study of volcanic rocks or fossil faunas.

These are some of the ways in which the study of the sediments and the sedimentary rocks can be forwarded not only by the special devotees of that branch of geology but also by anyone who takes an intelligent interest in the matter.